Free-Space Optical Link to an Explosive Ordnance Disposal (EOD) Robot

W.S. Rabinovich, J.L. Murphy, M. Suite, M.F. Ferraro, R. Mahon, and P.G. Goetz
Optical Sciences Division

Introduction: The Optical Sciences Division, in collaboration with scientists from the Remote Sensing Division and the Naval Center for Space Technology, field-tested a free-space optical (FSO) link for a counter-IED (improvised explosive device) robot. Traditional radio frequency (RF) link command and control of these robots is not possible in the presence of IED RF jammer systems. To solve this problem, a free-space optical link using quantum well based modulating retroreflectors was prototyped and installed on one version of a robot. Two field tests were run. During the first test at the Naval Explosive Ordnance Disposal Technology (NAVEODTECH) Division, Indian Head, the link operated in the presence of RF jammers and showed continued command and control on the robot without interference. The system was demonstrated to several military personnel including the Program Executive Officer (PEO) for Littoral and Mine Warfare. During the second test, at Naval Surface Warfare Center Dahlgren, the link was tested for range. A maximum range of 1 km, limited by line of sight, was demonstrated. This matches the maximum range for the RF link.

Free-space optical communication has emerged in recent years as an attractive alternative to conventional RF techniques due to its very large bandwidth, low probability of intercept, and immunity from interference or jamming. These features are inherent in the short wavelength of optics, but to be exploited, require high quality telescopes and extremely accurate pointing and tracking. As a result, optical communication systems can have a large system impact in terms of weight, power, and platform stability, which may be unacceptable for small platforms. Small, remotely controlled robots fall into this category of platforms. They often require high bandwidth links to return video and other data, but they may also work in environments in which a large amount of RF interference may be present, limiting their communication range. However, a conventional optical communication system may not be appropriate for them. Even for modest ranges on the order of 1 km and data rates on the order of 1.5 Mbps, a conventional FSO system will require pointing accuracy on the order of a degree for the transmitter and receiver. This implies that a gimbaled optical system with an automated acquisition and pointing system is needed on the robot.

In this effort, as an alternative to a conventional FSO system, we investigated the use of a retroreflecting optical system. It is possible to establish a two-way optical link using a single conventional laser transmitter. This transmitter is located on a large platform (or at a ground station) that has sufficient power, payload capacity, and platform stability to operate it. It can communicate data to a second, small platform conventionally by modulating its laser with the desired signal. If the laser is strong enough, the small platform can receive the data using a detector with a wide field of view, obviating the need for a large pointed receive telescope. However, such a system does not allow the small platform to transmit data back to the large platform. To do this, we used a modulating retroreflector (MRR).

An optical retroreflector is a passive optical component, such as a corner cube prism, that reflects light incident upon it exactly back along its path of incidence. Retroreflectors typically have a large field of view (about 30 degrees full angle for glass retroreflectors) and very high efficiency. Retroreflectors are often used in road signs to increase their readability at night.

Retroreflectors can also act as optical communication systems. By mounting an electro-optic shutter in front of the corner cube, the retroreflected beam can be modulated with the data signal. In operation, the large platform illuminates the small platform with a continuous-wave (unmodulated) laser beam. This beam strikes the modulating retroreflector and is passively reflected back to the large platform. The shutter is then turned on and off with an electrical signal that carries the small platform's data. This impresses the data stream upon the retroreflected beam, which then carries it back to the large platform. Figure 1 shows a schematic of a modulating retroreflector. For the past ten years, NRL

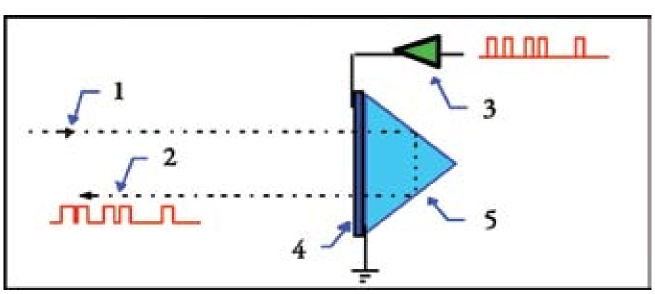

FIGURE 1
A modulating retroreflector diagram: (1) interrogation beam; (2) reflected modulated beam; (3) driver from the information source; (4) transmissive multiple quantum well modulator; and (5) solid retroreflector.

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has developed MRR systems using large area semiconductor multiple quantum well modulators.[1,2] These sophisticated solid state devices can operate at the Mbps data rates needed for transmitting video imagery.

Modulating Retroreflector Terminal for the Packbot: In the summer of 2008, NRL, working in collaboration with the NAVEODTECH Division, conducted a rapid prototyping experiment to test the feasibility of using MRR links for explosive ordnance disposal (EOD) robots, specifically the Packbot. The Packbot currently uses a 1.5 Mbps 802.11 RF link between its control station and the robot to return video from the Packbot's cameras and to send commands to the Packbot.

We created an MRR terminal with six MRR/photoreceiver elements, giving an angular coverage of 180° in azimuth and 30° in elevation. Full 360° coverage can be accomplished with more MRRs. All the modulators were driven with the same signal, for a total power draw of about 1.2 W. The MRR terminal created for the Packbot had a diameter of about six inches and is shown in Fig. 2. An Ethernet modem that was developed to drive MRRs interfaced the Packbot's data link to the MRR array.

An MRR free-space optical link is inherently asymmetric. It can use a small unpointed terminal on one end, but it requires an actively pointed laser interrogator on the other. We chose to use a laser interrogator developed for NRL under the ONR Dual Mode Optical Interrogator (DMOI) program. This terminal is shown in Fig. 2.

Optical Link Tests: Our initial link tests were conducted at the NAVEODTECH facility in Indian Head, MD. The Packbot was first set up in a field, and the optical link was established starting at ranges of about 30 m. The Packbot was then driven over the field out to ranges of about 250 m, limited by line-of-sight distances. Video return over the optical link was smooth over the whole range, as was control of driving. The robot could be turned ±90° without moving out of the field of view of the MRR terminal. At full range, the actuator arms were controlled over the optical link by both NRL operators and EOD personnel. Operation was essentially identical to operation over the Packbot RF link. Figure 3 is a photograph of the Packbot while being controlled by the optical link, along with the control console. At a later point in the day, a separate demonstration that used a small RF jammer was conducted. The jammer was turned on and the Packbot was driven, under its RF link, as close as we could get to the jammer. At a range of about 20 m from the jammer, the RF link failed. We then switched to the optical link and drove the Packbot up to the jammer and around it.

The primary tests of the Packbot-MRR optical link were conducted at Naval Surface Warfare Center Dahlgren, down Shock Tube road. This road provided a 1 km line of sight. We were able to control the robot over the full length of the road, even at distances at which the primary RF link could not work.

These tests demonstrated that an optical link could act as a drop-in replacement for an RF robot data link. The bandwidth allowed full video to be returned from the robot, which is needed for driver feedback. Future work will examine even more compact systems and approaches to non-line-of-sight links.

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(a)

(b)

FIGURE 2
(a) The EOD Packbot robot carrying the modulating retroreflector array and (b) the Novasol Dual Mode Optical Interrogator (DMOI) used in the experiment.

(a) (b)

FIGURE 3
Packbot, with MRR terminal mounted aft, being controlled by the optical link (a) and a view of the control console (b) while conducting tests at NAVEODTECH at Indian Head, MD.

the modulating retroreflectors and photoreceivers used in this project. We also acknowledge Wade Freeman, Steve Frawley, and Mike Colbert of SmartLogic, Inc. for modem development, and Eric Saint-George, Stan Uecke, and John Sender of Novasol for the DMOI optical interrogator.

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References

[1] G.C. Gilbreath, W.S. Rabinovich, R. Mahon, M.R. Corson, M. Ferraro, D.S. Katzer, K. Ikossi-Anastasiou, T. Meehan, and J.F. Kline, "Large Aperture Quantum Well Shutters for Fast Retroreflected Optical Data Links in Free Space," in *Laser Radar Technology and Applications IV,* held in Orlando, FL, and Munich, Germany, June 16, 1999, ed. G.W. Kamerman and C. Werner, *Proc. SPIE* **3707**, 666–672 (1999).

[2] W.S. Rabinovich, R. Mahon, H.R. Burris, G.C. Gilbreath, P.G. Goetz, C.I. Moore, M.F. Stell, M.J. Vilcheck, J.L. Witkowsky, L. Swingen, M.R. Suite, E. Oh, and J. Koplow, "Free-space Optical Communications Link at 1550 nm Using Multiple-quantum-well Modulating Retro-reflectors in a Marine Environment," *Opt. Eng.* **44**(5), 056001 (2005).